

NASA Technical Memorandum 104109

1N-02  
39577  
p. 54

**USER'S GUIDE TO A SYSTEM OF FINITE-ELEMENT SUPERSONIC  
PANEL FLUTTER PROGRAMS**

(NASA-TM-104109) USER'S GUIDE TO A SYSTEM  
OF FINITE-ELEMENT SUPERSONIC PANEL FLUTTER  
PROGRAMS (NASA) 54 p CSCL 01A

N91-31082

Unclass

G3/02 0039577

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**JULY 1991**



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# USER'S GUIDE TO A SYSTEM OF FINITE-ELEMENT SUPERSONIC PANEL FLUTTER PROGRAMS

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## SUMMARY

The utilization and operation of a set of six computer programs for the prediction of panel flutter at supersonic speeds by finite-element methods are described. The programs run individually to determine the flutter behavior of a flat panel where the finite-elements which model the panel each have four degrees-of-freedom, a curved panel where the finite-elements each have four degrees-of-freedom, and a curved panel where the finite-elements each have six degrees-of-freedom. The panels are assumed to be of infinite aspect ratio and are subjected to either simply-supported or clamped boundary conditions. The aerodynamics used by these programs are based on piston theory. Application of the programs is illustrated by sample cases where the number of beam finite-elements equals four, the in-plane tension parameter is 0.0, the maximum camber to panel length ratio for a curved panel case is 0.05, and the Mach number is 2.0. This memorandum provides a user's guide for these programs, describes the parameters that are used, and contains sample output from each of the programs.

## INTRODUCTION

Considerable progress has been made over the years in developing an understanding of panel flutter, which is an aeroelastic instability that sometimes occurs for thin panels at supersonic speeds.<sup>1,2</sup> To aid in this understanding, computer programs have been developed to predict panel flutter. The methods that these programs are based on are of current importance because of the interest in aircraft that fly at supersonic speeds such as the National Aero-Space Plane. A system of such computer programs has been developed (unpublished work of the second author, 1980), similar to the methods described in Refs. 3 and 4, to approximate supersonic panel flutter for thin panels of infinite aspect ratio using beam finite-elements and a simple bisection technique to iterate to find flutter. The purpose of this memorandum is to provide a user's guide for these computer programs, including a description of each program, definitions of the parameters used in the programs, and sample output.

## GENERAL DESCRIPTION

The set of six computer programs, described briefly in the following paragraphs, provides a supersonic flutter approximation for both flat and curved panels of infinite aspect ratio. Since the aerodynamics are based on piston theory, the programs are restricted to approximate two-dimensional panel flutter for Mach number greater than about 1.6.

Program PANEL1 determines the flutter point for a flat panel at supersonic speeds subjected to either simply-supported or clamped boundary conditions, similar to the methods described in Refs. 3 and 4. The flat panel may be divided into a specified number of elements of equal length, each having four degrees-of-freedom. The four degrees-of-freedom include vertical deflection and rotation at each end of the element. This program determines the flutter point of the panel when it experiences no in-plane tension ( $RXX=0.0$ ), in-plane tension ( $RXX>0.0$ ), or in-plane compression ( $RXX<0.0$ ). A user's guide and a more thorough description of program PANEL1 are provided in Appendix A.

Program PANEL2A determines the complete flutter boundary for a simply-supported flat panel that may be divided into a specified number of elements of equal length, each having four degrees-of-freedom. This program solves a slightly different eigenvalue problem than that solved by program PANEL1, to allow comparison with results published in Ref. 5. The flutter boundaries of the panel when it experiences no in-plane tension ( $F=0.0$ ), in-plane tension ( $F>0.0$ ), or in-plane compression ( $F<0.0$ ) are determined by this program. Appendix B contains a user's guide and a more detailed description of program PANEL2A.

Program PANEL2B determines the complete flutter boundary for a clamped flat panel that may be divided into a specified number of elements of equal length, each having four degrees-of-freedom. This program solves a slightly different eigenvalue problem than that solved by program PANEL1, to allow comparison with results published in Ref. 5. The flutter boundaries of the panel when it experiences no in-plane tension ( $F=0.0$ ), in-plane tension ( $F>0.0$ ), or in-plane compression ( $F<0.0$ ) are approximated by this program. Program PANEL2B is described in more detail in Appendix C where a user's guide is also available.

Program PANEL3 is a supersonic flutter approximation for a curved panel with circular arc cross-section subjected to either simply-supported or clamped boundary conditions. The curved panel may be divided into a specified number of elements of equal arclength, each having four degrees-of-freedom. The flutter point of the panel may be determined for various values of the ratio of maximum camber to panel length. A user's guide and a more detailed description of program PANEL3 are given in Appendix D.

Program PANEL4 is a supersonic flutter approximation for a curved panel with circular arc cross-section subjected to either simply-supported or clamped boundary conditions. The curved panel may be divided into a specified number of elements of equal arclength, each having six degrees-of-freedom. The six degrees-of-freedom include vertical deflection, horizontal deflection, and rotation at each end of the element. The flutter point of the panel for various values of the ratio of maximum camber to panel length is determined by this program. Appendix E contains a user's guide and a more thorough description of program PANEL4.

Program TRESPAN is a transient response analysis for a flat panel subjected to a supersonic flow and either simply-supported or clamped boundary conditions. TRESPAN requires input

values determined from the solution produced by program PANEL1, to determine stability in the time domain. A user's guide and a more thorough description of program TRESPAN is provided in Appendix F.

These programs, along with several output data files for each one, are stored presently in a permanent directory named FLUTTER on the Cray-2 (Voyager) computer at NASA Langley Research Center. The programs, however, do not require the large memory and speed of a supercomputer. They are written in standard fortran 77 and are thus executable on most computer systems.

## APPENDIX A

### PROGRAM PANEL1

Program PANEL1 is a finite-element supersonic flutter approximation for flat panels of infinite aspect ratio subjected to either simply-supported or clamped boundary conditions. The flat panel can be divided into a specified number of beam finite-elements of equal length, each having four degrees-of-freedom. The four degrees-of-freedom include vertical deflection and rotation at each end of the element.

The purpose of program PANEL1 is to solve the eigenproblem represented by

$$\left[ [K] + R_{xx} \frac{\pi^2}{N^2} [N] + \frac{\lambda}{N^3} [A] \right] \{w\} = \frac{K}{N^4} [M] \{w\}$$

where

$$\lambda = \frac{2qL^3}{D\sqrt{M^2 - 1}}$$

$[K]$  = Global stiffness matrix

$[N]$  = Global incremental stiffness matrix

$[A]$  = Global aerodynamic matrix

$[M]$  = Global mass matrix

$R_{xx}$  = Nondimensional in-plane tension parameter

$N$  = Number of finite elements

$q$  is the dynamic pressure,  $D$  is the panel rigidity,  $M$  is the freestream Mach number, and  $K$  is the eigenvalue of the system for monotonically increasing values of the nondimensional dynamic pressure parameter,  $\lambda$ . Typical element stiffness, incremental stiffness, aerodynamic, and mass matrices found in the corresponding global matrices are given by

$$[k] = \frac{D}{l^3} \begin{bmatrix} 12 & -6l & -12 & -6l \\ -6l & 4l^2 & 6l & 2l^2 \\ -12 & 6l & 12 & 6l \\ -6l & 2l^2 & 6l & 4l^2 \end{bmatrix}$$

$$[n] = \frac{R_{xx}}{l} \begin{bmatrix} 6/5 & -l/10 & -6/5 & -l/10 \\ -l/10 & 2l^2/15 & l/10 & -l^2/30 \\ -6/5 & l/10 & 6/5 & l/10 \\ -l/10 & -l^2/30 & l/10 & 2l^2/15 \end{bmatrix}$$



$$[a] = \frac{2q}{\sqrt{M^2 - 1}} \begin{bmatrix} -1/2 & -l/10 & 1/2 & l/10 \\ l/10 & 0 & -l/10 & -l^2/60 \\ -1/2 & l/10 & 1/2 & -l/10 \\ -l/10 & l^2/60 & l/10 & 0 \end{bmatrix}$$

$$[m] = \frac{\rho A}{420} \begin{bmatrix} 156 & -22l & 54 & 13l \\ -22l & 4l^2 & -13l & -3l^2 \\ 54 & -13l & 156 & 22l \\ 13l & -3l^2 & 22l & 4l^2 \end{bmatrix}$$

where  $\rho$  is the panel density,  $A$  is the area of the cross section per unit width, and  $l$  is the element length. See Refs. 3 and 4 for further details. The program determines the flutter point of the flat panel by coalescence of the two smallest eigenvalues for these increasing values of  $\lambda$ . Figure 1 demonstrates this coalescence of eigenvalues for an increasing number of beam finite-elements ( $N=1$  to  $N=4$ ) for both the simply-supported (Figure 1(a)) and the clamped (Figure 1(b)) cases. A comparison of the numerical results obtained when  $N=3$  with those obtained when  $N=4$  shows that the two data sets are very close in value for both cases. This suggests that the results are nearly converged when using only four elements. The listing of sample output for  $N=4$  indicates that  $\lambda=342$  and  $\lambda=639$  at flutter for the simply-supported and clamped cases, respectively.

In addition to determining the flutter point of the flat panel, program PANEL1 also determines the flutter mode shape and offers a comparison of this result with that obtained by J. C. Houbolt<sup>6</sup> in his Doctoral Thesis. An example is given in the sample output for a simply-supported panel at a condition beyond the flutter point corresponding to  $\lambda=364$ .

Twelve of the arrays used in program PANEL1 must be dimensioned according to the number of beam finite-elements used with the maximum number of finite-elements presently limited to ten. These arrays must be dimensioned as follows:

XSS(2N,2N)	XCL(2N-2,2N-2)
MSS(2N,2N)	MCL(2N-2,2N-2)
WSS(2N)	WCL(2N-2)
ALPHASS(2N)	ALPHACL(2N-2)
GAMMASS(2N)	GAMMACL(2N-2)
ZSS(2N,2N)	ZCL(2N-2,2N-2)

The definitions of these arrays may be found in Appendix I (Definitions of Parameters Used in Programs).

The output data files for program PANEL1, stored in the permanent directory FLUTTER, are named according to the following format:

panel1.n#rxx

where # is the number of beam finite-elements used and rxx is the in-plane tension parameter used (a 0 represents no in-plane tension, a 1 represents in-plane tension, and a -1 represents in-plane compression). For example, if the file containing output data for the sample case where four beam finite-elements experience no in-plane tension is to be viewed, the correct syntax of the output data file name is panel1.n40. A condensed listing of this sample output data file can be found on the following pages.

[illegible][illegible][illegible]

# LISTING OF SAMPLE OUTPUT

## PROGRAM PANEL1

\*\*\*\*\*  
\*\*\*\*\* SUPERSONIC PANEL FLUTTER ANALYSIS (PANEL1) \*\*\*\*\*  
\*\*\*\*\*

N= 4      RXX=0.0

\*\*\*\*\*SIMPLY-SUPPORTED BOUNDARY CONDITION\*\*\*\*\*

LAMBDA= 0.000

K(1)=	97.45968	0.00000
K(2)=	1570.87257	0.00000

LAMBDA= 10.000

K(1)=	97.94575	0.00000
K(2)=	1570.73953	0.00000

LAMBDA= 20.000

K(1)=	99.40478	0.00000
K(2)=	1570.33959	0.00000

LAMBDA= 30.000

K(1)=	101.83935	0.00000
K(2)=	1569.67033	0.00000

LAMBDA= 40.000

K(1)=	105.25374	0.00000
K(2)=	1568.72766	0.00000

LAMBDA= 50.000

K(1)=	109.65404	0.00000
K(2)=	1567.50577	0.00000

\*\*\*\*\*FLUTTER POINT (EIGENVALUE COALESCENCE)\*\*\*\*\*

LAMBDA= 342.347

K(1)=	1043.47047	0.00000
K(2)=	1043.47102	0.00000

\*\*\*\*\*FLUTTER MODE SHAPE\*\*\*\*\*

W( 1)=	-0.11275	0.00000
W( 2)=	0.05256	0.00000
W( 3)=	0.07875	0.00000
W( 4)=	-0.24561	0.00000
W( 5)=	0.48039	0.00000
W( 6)=	-0.59766	0.00000
W( 7)=	-0.00937	0.00000
W( 8)=	-1.00000	0.00000

\*\*\*\*\*HOUBOLT FLUTTER MODE COMPARISON\*\*\*\*\*

LAMBDA= 364.310

K(1)=	1071.56543	-270.56823
K(2)=	1071.56543	270.56823

\*\*\*\*\*FLUTTER MODE SHAPE\*\*\*\*\*

W( 1)=	0.10935	0.06136
W( 2)=	-0.05419	-0.06060
W( 3)=	-0.06921	0.05033
W( 4)=	0.23181	-0.07278
W( 5)=	-0.47264	-0.03180
W( 6)=	0.58930	-0.02015
W( 7)=	-0.00577	-0.04969
W( 8)=	1.00000	0.00000

\*\*\*\*\*CLAMPED BOUNDARY CONDITION\*\*\*\*\*

LAMBDA= 0.000

K(1)=	501.89357	0.00000
K(2)=	3874.22601	0.00000

LAMBDA= 10.000

K(1)=	502.22588	0.00000
K(2)=	3874.15244	0.00000

LAMBDA= 20.000

K(1)=	503.22298	0.00000
K(2)=	3873.93157	0.00000

LAMBDA= 30.000

K(1)=	504.88536	0.00000
K(2)=	3873.56294	0.00000

LAMBDA= 40.000

K(1)=	507.21387	0.00000
K(2)=	3873.04578	0.00000

LAMBDA= 50.000

K(1)=	510.20969	0.00000
K(2)=	3872.37899	0.00000

\*\*\*\*\*FLUTTER POINT (EIGENVALUE COALESCENCE)\*\*\*\*\*

LAMBDA= 636.437

K(1)=	2721.37556	0.00000
K(2)=	2721.37663	0.00000

\*\*\*\*\*FLUTTER MODE SHAPE\*\*\*\*\*

W( 1)=	-0.10692	0.00000
W( 2)=	-0.02536	0.00000
W( 3)=	0.43323	0.00000
W( 4)=	-0.99505	0.00000
W( 5)=	1.00000	0.00000
W( 6)=	0.43789	0.00000

\*\*\*\*\*HOUBOLT FLUTTER MODE COMPARISON\*\*\*\*\*

LAMBDA= 648.745

K(1)=	2742.59655	337.96527
K(2)=	2742.59655	-337.96527

\*\*\*\*\*FLUTTER MODE SHAPE\*\*\*\*\*

W( 1)=	-0.10935	-0.04236
W( 2)=	-0.01358	0.07139
W( 3)=	0.42560	-0.09009
W( 4)=	-1.00000	0.00000
W( 5)=	1.00627	-0.04370
W( 6)=	0.42899	-0.06869

## APPENDIX B

### PROGRAM PANEL2A

Program PANEL2A is a finite-element supersonic flutter approximation for flat panels of infinite aspect ratio subjected to simply-supported boundary conditions. The flat panel may be divided into a specified number of elements of equal length, each having four degrees-of-freedom. The four degrees-of-freedom include vertical deflection and rotation at each end of the element.

The purpose of program PANEL2A is to solve the eigenproblem represented by

$$\left[ \frac{N[M]}{1/\mu} - \frac{1}{K_L^2} \frac{N^2}{\sqrt{M^2 - 1}} [A] \right] \{w\} = \Omega \left[ \frac{N^5}{1/\mu} \frac{1}{\pi^4} [K] + \frac{FN^3}{1/\mu} [N] \right] \{w\}$$

where

- $[M]$  = Global mass matrix
- $[A]$  = Global aerodynamic matrix
- $[K]$  = Global stiffness matrix
- $[N]$  = Global incremental stiffness matrix
- $N$  = Number of finite elements
- $M$  = Mach number
- $F$  = Nondimensional in-plane tension parameter

and  $\Omega$  is the nondimensional natural frequency of the panel for monotonically increasing values of the air-panel mass ratio,  $1/\mu$ , and the reduced frequency,  $K_L$ .

To achieve flutter boundary results similar in nature to those obtained by Yang and Sung,<sup>5</sup> in terms of the stiffness parameter,  $\omega_1 L/V$ , a variable conversion must be employed. Using the values of  $\Omega$  obtained through solution of the eigenproblem, along with the monotonically increasing values of the reduced frequency,  $K_L$ , the stiffness parameter may be computed as

$$\frac{\omega_1 L}{V} = K_L \sqrt{\Omega}.$$

A variable conversion may also be used to determine the flutter boundaries for the results obtained in program PANEL1. Using the values of the nondimensional dynamic pressure parameter,  $\lambda$ , obtained in program PANEL1 for the simply-supported case, along with the monotonically increasing values of the air-panel mass ratio,  $1/\mu$ , the stiffness parameter and the reduced frequency may be computed as

$$\frac{\omega_1 L}{V} = \pi^2 \sqrt{\frac{1}{\lambda} \frac{1}{\sqrt{M^2 - 1}}}$$

and

$$K_L = \frac{1}{\pi^2} \frac{\omega_1 L}{V} \sqrt{K}$$

where  $K$  is the eigenvalue at the flutter point obtained in program PANEL1. The usefulness of converting program PANEL1 data to determine the flutter boundaries is demonstrated in Figure 2. This figure shows the effects of Mach number on the stability of the flat panel. As Mach number is increased, the stability of the flat panel is increased.

The stability of the flat panel may also be studied by looking at the effects of in-plane tension on the panel when it is simply-supported. Using the data obtained from program PANEL1 when the nondimensional in-plane tension parameter is varied, it can be seen that when the panel is put under tension ( $F=1.0$ ), the flutter value of the dynamic pressure parameter increases and, therefore, the panel becomes more stable. Conversely, when the panel is put under compression ( $F=-1.0$ ), the flutter value of the dynamic pressure parameter decreases and the panel becomes less stable.

Five of the arrays used in program PANEL2A must be dimensioned according to the number of beam finite-elements used with the maximum number of finite-elements currently limited to ten. These arrays must be dimensioned as follows:

XSS(2N,2N)  
YSS(2N,2N)  
WSS(2N)  
ALPHASS(2N)  
GAMMASS(2N)

The definitions of these arrays may be found in Appendix I (Definitions of Parameters Used in Programs).

The output data files for program PANEL2A, stored in the permanent directory FLUTTER, are named according to the following format:

## panel2a.n#fm

where # is the number of beam finite-elements used, f is the in-plane tension parameter used (a 0 represents no in-plane tension, a 1 represents in-plane tension, and a -1 represents in-plane compression), and m is the Mach number used. For example, if the file containing output data for the sample case where four beam finite-elements experience no in-plane tension at a Mach number of 2.0 is to be viewed, the correct syntax of the output data file name is panel2a.n402. A condensed listing of this sample output data file can be found on the following pages.



# LISTING OF SAMPLE OUTPUT

## PROGRAM PANEL2A

```
*****
***** SUPersonic PANEL FLUTTER ANALYSIS (PANEL2A) *****
*****
```

N= 4      F=0.000      MACH=2.000

```
*****SIMPLY-SUPPORTED BOUNDARY CONDITION*****
```

1/MU= 0.010

KL= 0.075

OMEGA( 1)= 0.97614E-01	0.23498E+00	K1= 0.23432E-01
OMEGA( 2)= 0.97614E-01	-0.23498E+00	K1= 0.23432E-01
OMEGA( 3)= 0.32765E+00	-0.11629E+01	K1= 0.42930E-01
OMEGA( 4)= 0.32765E+00	0.11629E+01	K1= 0.42930E-01
OMEGA( 5)= 0.20575E+01	0.53131E+01	K1= 0.10758E+00
OMEGA( 6)= 0.20575E+01	-0.53131E+01	K1= 0.10758E+00
OMEGA( 7)= 0.50055E+02	-0.48532E+02	K1= 0.53062E+00
OMEGA( 8)= 0.50055E+02	0.48532E+02	K1= 0.53062E+00

KL= 0.125

OMEGA( 1)= 0.91268E-01	-0.68651E-01	K1= 0.37763E-01
OMEGA( 2)= 0.91268E-01	0.68651E-01	K1= 0.37763E-01
OMEGA( 3)= 0.29728E+00	0.31492E+00	K1= 0.68154E-01
OMEGA( 4)= 0.29728E+00	-0.31492E+00	K1= 0.68154E-01
OMEGA( 5)= 0.16673E+01	0.96326E+00	K1= 0.16140E+00
OMEGA( 6)= 0.16673E+01	-0.96326E+00	K1= 0.16140E+00
OMEGA( 7)= 0.10387E+02	0.00000E+00	K1= 0.40287E+00
OMEGA( 8)= 0.90576E+02	0.00000E+00	K1= 0.11896E+01

KL= 0.175

OMEGA( 1)= 0.71938E-01	-0.14273E-01	K1= 0.46937E-01
OMEGA( 2)= 0.71938E-01	0.14273E-01	K1= 0.46937E-01
OMEGA( 3)= 0.19893E+00	0.00000E+00	K1= 0.78053E-01
OMEGA( 4)= 0.23463E+00	0.00000E+00	K1= 0.84768E-01
OMEGA( 5)= 0.57230E+00	0.00000E+00	K1= 0.13239E+00
OMEGA( 6)= 0.15637E+01	0.00000E+00	K1= 0.21884E+00
OMEGA( 7)= 0.66715E+01	0.00000E+00	K1= 0.45201E+00
OMEGA( 8)= 0.95690E+02	0.00000E+00	K1= 0.17119E+01

1/MU= 0.020

KL= 0.075

OMEGA( 1)=	0.98324E-01	-0.48028E+00	K1= 0.23517E-01
OMEGA( 2)=	0.98324E-01	0.48028E+00	K1= 0.23517E-01
OMEGA( 3)=	0.33110E+00	-0.23939E+01	K1= 0.43156E-01
OMEGA( 4)=	0.33110E+00	0.23939E+01	K1= 0.43156E-01
OMEGA( 5)=	0.20994E+01	0.11267E+02	K1= 0.10867E+00
OMEGA( 6)=	0.20994E+01	-0.11267E+02	K1= 0.10867E+00
OMEGA( 7)=	0.50009E+02	0.12707E+03	K1= 0.53038E+00
OMEGA( 8)=	0.50009E+02	-0.12707E+03	K1= 0.53038E+00

KL= 0.125

OMEGA( 1)=	0.96734E-01	-0.16462E+00	K1= 0.38878E-01
OMEGA( 2)=	0.96734E-01	0.16462E+00	K1= 0.38878E-01
OMEGA( 3)=	0.32338E+00	0.80728E+00	K1= 0.71083E-01
OMEGA( 4)=	0.32338E+00	-0.80728E+00	K1= 0.71083E-01
OMEGA( 5)=	0.20039E+01	0.35432E+01	K1= 0.17695E+00
OMEGA( 6)=	0.20039E+01	-0.35432E+01	K1= 0.17695E+00
OMEGA( 7)=	0.50114E+02	0.12080E+02	K1= 0.88489E+00
OMEGA( 8)=	0.50114E+02	-0.12080E+02	K1= 0.88489E+00

KL= 0.175

OMEGA( 1)=	0.91556E-01	0.70762E-01	K1= 0.52952E-01
OMEGA( 2)=	0.91556E-01	-0.70762E-01	K1= 0.52952E-01
OMEGA( 3)=	0.29863E+00	0.32591E+00	K1= 0.95632E-01
OMEGA( 4)=	0.29863E+00	-0.32591E+00	K1= 0.95632E-01
OMEGA( 5)=	0.16838E+01	-0.10234E+01	K1= 0.22708E+00
OMEGA( 6)=	0.16838E+01	0.10234E+01	K1= 0.22708E+00
OMEGA( 7)=	0.10655E+02	0.00000E+00	K1= 0.57124E+00
OMEGA( 8)=	0.90272E+02	0.00000E+00	K1= 0.16627E+01

1/MU= 0.03

KL= 0.075

OMEGA( 1)=	0.98456E-01	0.72330E+00	K1= 0.23533E-01
OMEGA( 2)=	0.98456E-01	-0.72330E+00	K1= 0.23533E-01
OMEGA( 3)=	0.33174E+00	-0.36098E+01	K1= 0.43198E-01
OMEGA( 4)=	0.33174E+00	0.36098E+01	K1= 0.43198E-01
OMEGA( 5)=	0.21070E+01	0.17079E+02	K1= 0.10887E+00
OMEGA( 6)=	0.21070E+01	-0.17079E+02	K1= 0.10887E+00
OMEGA( 7)=	0.50000E+02	-0.19784E+03	K1= 0.53033E+00
OMEGA( 8)=	0.50000E+02	0.19784E+03	K1= 0.53033E+00

KL= 0.125

OMEGA( 1)=	0.97749E-01	-0.25483E+00	K1= 0.39081E-01
OMEGA( 2)=	0.97749E-01	0.25483E+00	K1= 0.39081E-01
OMEGA( 3)=	0.32830E+00	0.12629E+01	K1= 0.71622E-01
OMEGA( 4)=	0.32830E+00	-0.12629E+01	K1= 0.71622E-01
OMEGA( 5)=	0.20655E+01	0.58038E+01	K1= 0.17965E+00
OMEGA( 6)=	0.20655E+01	-0.58038E+01	K1= 0.17965E+00
OMEGA( 7)=	0.50046E+02	0.55855E+02	K1= 0.53033E+00
OMEGA( 8)=	0.50046E+02	-0.55855E+02	K1= 0.53033E+00

KL= 0.175

OMEGA( 1)=	0.95442E-01	-0.12092E+00	K1= 0.54064E-01
OMEGA( 2)=	0.95442E-01	0.12092E+00	K1= 0.54064E-01
OMEGA( 3)=	0.31714E+00	0.58465E+00	K1= 0.98551E-01
OMEGA( 4)=	0.31714E+00	-0.58465E+00	K1= 0.98551E-01
OMEGA( 5)=	0.19232E+01	-0.24016E+01	K1= 0.24269E+00
OMEGA( 6)=	0.19232E+01	0.24016E+01	K1= 0.24269E+00
OMEGA( 7)=	0.21330E+02	0.00000E+00	K1= 0.80823E+00
OMEGA( 8)=	0.79074E+02	0.00000E+00	K1= 0.15562E+01

1/MU= 0.040

KL= 0.075

OMEGA( 1)=	0.98502E-01	0.96574E+00	K1= 0.23539E-01
OMEGA( 2)=	0.98502E-01	-0.96574E+00	K1= 0.23539E-01
OMEGA( 3)=	0.33196E+00	0.48220E+01	K1= 0.43212E-01
OMEGA( 4)=	0.33196E+00	-0.48220E+01	K1= 0.43212E-01
OMEGA( 5)=	0.21097E+01	-0.22856E+02	K1= 0.10894E+00
OMEGA( 6)=	0.21097E+01	0.22856E+02	K1= 0.10894E+00
OMEGA( 7)=	0.49997E+02	-0.26708E+03	K1= 0.53032E+00
OMEGA( 8)=	0.49997E+02	0.26708E+03	K1= 0.53032E+00

KL= 0.125

OMEGA( 1)=	0.98104E-01	0.34349E+00	K1= 0.39152E-01
OMEGA( 2)=	0.98104E-01	-0.34349E+00	K1= 0.39152E-01
OMEGA( 3)=	0.33003E+00	0.17084E+01	K1= 0.71810E-01
OMEGA( 4)=	0.33003E+00	-0.17084E+01	K1= 0.71810E-01
OMEGA( 5)=	0.20865E+01	-0.79689E+01	K1= 0.18056E+00
OMEGA( 6)=	0.20865E+01	0.79689E+01	K1= 0.18056E+00
OMEGA( 7)=	0.50023E+02	-0.85380E+02	K1= 0.83409E+00
OMEGA( 8)=	0.50023E+02	0.85380E+02	K1= 0.83409E+00

KL= 0.175

OMEGA( 1)=	0.96806E-01	0.16836E+00	K1=	0.54449E-01
OMEGA( 2)=	0.96806E-01	-0.16836E+00	K1=	0.54449E-01
OMEGA( 3)=	0.32373E+00	-0.82626E+00	K1=	0.99570E-01
OMEGA( 4)=	0.32373E+00	0.82626E+00	K1=	0.99570E-01
OMEGA( 5)=	0.20084E+01	0.36390E+01	K1=	0.24800E+00
OMEGA( 6)=	0.20084E+01	-0.36390E+01	K1=	0.24800E+00
OMEGA( 7)=	0.50109E+02	-0.15613E+02	K1=	0.12388E+01
OMEGA( 8)=	0.50109E+02	0.15613E+02	K1=	0.12388E+01

1/MU= 0.050

KL= 0.075

OMEGA( 1)=	0.98523E-01	0.12080E+01	K1=	0.23541E-01
OMEGA( 2)=	0.98523E-01	-0.12080E+01	K1=	0.23541E-01
OMEGA( 3)=	0.33207E+00	0.60326E+01	K1=	0.43219E-01
OMEGA( 4)=	0.33207E+00	-0.60326E+01	K1=	0.43219E-01
OMEGA( 5)=	0.21109E+01	0.28618E+02	K1=	0.10897E+00
OMEGA( 6)=	0.21109E+01	-0.28618E+02	K1=	0.10897E+00
OMEGA( 7)=	0.49996E+02	-0.33575E+03	K1=	0.53031E+00
OMEGA( 8)=	0.49996E+02	0.33575E+03	K1=	0.53031E+00

KL= 0.125

OMEGA( 1)=	0.98268E-01	-0.43152E+00	K1=	0.39185E-01
OMEGA( 2)=	0.98268E-01	0.43152E+00	K1=	0.39185E-01
OMEGA( 3)=	0.33083E+00	0.21497E+01	K1=	0.71897E-01
OMEGA( 4)=	0.33083E+00	-0.21497E+01	K1=	0.71897E-01
OMEGA( 5)=	0.20962E+01	0.10095E+02	K1=	0.18098E+00
OMEGA( 6)=	0.20962E+01	-0.10095E+02	K1=	0.18098E+00
OMEGA( 7)=	0.50012E+02	-0.11249E+03	K1=	0.88399E+00
OMEGA( 8)=	0.50012E+02	0.11249E+03	K1=	0.88399E+00

KL= 0.175

OMEGA( 1)=	0.97438E-01	0.21463E+00	K1=	0.54626E-01
OMEGA( 2)=	0.97438E-01	-0.21463E+00	K1=	0.54626E-01
OMEGA( 3)=	0.32679E+00	0.10603E+01	K1=	0.10004E+00
OMEGA( 4)=	0.32679E+00	-0.10603E+01	K1=	0.10004E+00
OMEGA( 5)=	0.20469E+01	-0.48070E+01	K1=	0.25037E+00
OMEGA( 6)=	0.20469E+01	0.48070E+01	K1=	0.25037E+00
OMEGA( 7)=	0.50066E+02	0.40450E+02	K1=	0.12383E+01
OMEGA( 8)=	0.50066E+02	-0.40450E+02	K1=	0.12383E+01

## APPENDIX C

### PROGRAM PANEL2B

Program PANEL2B is a finite-element supersonic flutter approximation for flat panels of infinite aspect ratio subjected to clamped boundary conditions. The flat panel may be divided into a specified number of beam finite-elements of equal length, each having four degrees-of-freedom. The four degrees-of-freedom include vertical deflection and rotation at each end of the element.

The purpose of program PANEL2B is to solve the eigenproblem represented by

$$\left[ \frac{N[M]}{1/\mu} - \frac{1}{K_L^2} \frac{N^2}{\sqrt{M^2 - 1}} [A] \right] \{w\} = \Omega \left[ \frac{N^5}{1/\mu} \frac{1}{\pi^4} [K] + \frac{FN^3}{1/\mu} [N] \right] \{w\}$$

where

- $[M]$  = Global mass matrix
- $[A]$  = Global aerodynamic matrix
- $[K]$  = Global stiffness matrix
- $[N]$  = Global incremental stiffness matrix
- $N$  = Number of finite elements
- $M$  = Mach number
- $F$  = Nondimensional in-plane tension parameter

and  $\Omega$  is the nondimensional natural frequency of the panel for monotonically increasing values of the air-panel mass ratio,  $1/\mu$ , and the reduced frequency,  $K_L$ .

To achieve flutter boundary results similar in nature to those obtained by Yang and Sung,<sup>5</sup> in terms of the stiffness parameter,  $\omega_1 L/V$ , a variable conversion must be employed. Using the values of  $\Omega$  obtained through solution of the eigenproblem, along with the monotonically increasing values of the reduced frequency,  $K_L$ , the stiffness parameter may be computed as

$$\frac{\omega_1 L}{V} = K_L \sqrt{\Omega}.$$

A variable conversion may also be used to determine the flutter boundaries for the results obtained in program PANEL1. Using the values of the nondimensional dynamic pressure parameter,  $\lambda$ , obtained in program PANEL1 for the clamped case, along with the monotonically increasing values of the air-panel mass ratio,  $1/\mu$ , the stiffness parameter and the reduced frequency may be computed as

$$\frac{\omega_1 L}{V} = 4.73004^2 \sqrt{\frac{1}{\lambda} \frac{1}{\mu} \frac{1}{\sqrt{M^2 - 1}}}$$

and

$$K_L = \frac{1}{4.73004^2} \frac{\omega_1 L}{V} \sqrt{K}$$

where  $K$  is the eigenvalue at the flutter point. The usefulness of converting program PANEL1 data to determine the flutter boundaries is demonstrated in Figure 3. This figure shows the effects of Mach number on the stability of the flat panel. As Mach number is increased, the stability of the flat panel is increased.

The stability of the flat panel may also be studied by looking at the effects of in-plane tension on the panel when it is clamped. Using the data obtained from program PANEL1 when the non-dimensional in-plane tension parameter is varied, it can be seen that when the panel is put under tension ( $F=1.0$ ), the flutter point value of the dynamic pressure parameter increases and, therefore, the panel becomes more stable. Conversely, when the panel is put under compression ( $F=-1.0$ ), the flutter point value of the dynamic pressure parameter decreases and the panel becomes less stable.

Five of the arrays used in program PANEL2B must be dimensioned according to the number of beam finite-elements used with the maximum number of finite-elements currently limited to ten. These arrays must be dimensioned as follows:

XCL(2N-2,2N-2)

YCL(2N-2,2N-2)

WCL(2N-2)

ALPHACL(2N-2)

GAMMACL(2N-2)

The definitions of these arrays may be found in Appendix I (Definitions of Parameters Used in Programs).

The output data files for program PANEL2B, stored in the permanent directory FLUTTER, are named according to the following format:

panel2b.n#fm

where # is the number of beam finite-elements used, f is the in-plane tension parameter used (a 0 represents no in-plane tension, a 1 represents in-plane tension, and a -1 represents in-plane compression), and m is the Mach number used. For example, if the file containing output data for the sample case where four beam finite-elements experience no in-plane tension at a Mach number of 2.0 is to be viewed, the correct syntax of the output data file name is panel2b.n402. A condensed listing of this sample output data file can be found on the following pages.

# LISTING OF SAMPLE OUTPUT

## PROGRAM PANEL2B

\*\*\*\*\*  
 \*\*\*\*\* SUPERSONIC PANEL FLUTTER ANALYSIS (PANEL2B) \*\*\*\*\*  
 \*\*\*\*\*

N= 4 F=0.000 MACH=2.000

\*\*\*\*\*CLAMPED BOUNDARY CONDITION\*\*\*\*\*

1/MU= 0.010

KL= 0.075

OMEGA( 1)=	0.51843E+01	0.12771E+02	K1=	0.17077E+00
OMEGA( 2)=	0.51843E+01	-0.12771E+02	K1=	0.17077E+00
OMEGA( 3)=	0.24939E+02	-0.80415E+02	K1=	0.37454E+00
OMEGA( 4)=	0.24939E+02	0.80415E+02	K1=	0.37454E+00
OMEGA( 5)=	0.26351E+03	-0.59735E+03	K1=	0.12175E+01
OMEGA( 6)=	0.26351E+03	0.59735E+03	K1=	0.12175E+01

KL= 0.125

OMEGA( 1)=	0.47916E+01	-0.34715E+01	K1=	0.27362E+00
OMEGA( 2)=	0.47916E+01	0.34715E+01	K1=	0.27362E+00
OMEGA( 3)=	0.22892E+02	-0.20219E+02	K1=	0.59807E+00
OMEGA( 4)=	0.22892E+02	0.20219E+02	K1=	0.59807E+00
OMEGA( 5)=	0.22668E+03	0.00000E+00	K1=	0.18820E+01
OMEGA( 6)=	0.30521E+03	0.00000E+00	K1=	0.21838E+01

KL= 0.175

OMEGA( 1)=	0.30387E+01	0.00000E+00	K1=	0.30506E+00
OMEGA( 2)=	0.43093E+01	0.00000E+00	K1=	0.36328E+00
OMEGA( 3)=	0.10864E+02	0.00000E+00	K1=	0.57680E+00
OMEGA( 4)=	0.23359E+02	0.00000E+00	K1=	0.84579E+00
OMEGA( 5)=	0.78189E+02	0.00000E+00	K1=	0.15474E+01
OMEGA( 6)=	0.46750E+03	0.00000E+00	K1=	0.37838E+01

1/MU= 0.020

KL= 0.075

OMEGA( 1)=	0.52286E+01	0.26261E+02	K1=	0.17150E+00
OMEGA( 2)=	0.52286E+01	-0.26261E+02	K1=	0.17150E+00
OMEGA( 3)=	0.25145E+02	-0.16623E+03	K1=	0.37609E+00
OMEGA( 4)=	0.25145E+02	0.16623E+03	K1=	0.37609E+00
OMEGA( 5)=	0.26326E+03	-0.12632E+04	K1=	0.12169E+01
OMEGA( 6)=	0.26326E+03	0.12632E+04	K1=	0.12169E+01



KL= 0.125

OMEGA( 1)=	0.51295E+01	-0.88769E+01	K1= 0.28310E+00
OMEGA( 2)=	0.51295E+01	0.88769E+01	K1= 0.28310E+00
OMEGA( 3)=	0.24675E+02	0.55484E+02	K1= 0.62093E+00
OMEGA( 4)=	0.24675E+02	-0.55484E+02	K1= 0.62093E+00
OMEGA( 5)=	0.26382E+03	-0.39758E+03	K1= 0.20303E+01
OMEGA( 6)=	0.26382E+03	0.39758E+03	K1= 0.20303E+01

KL= 0.175

OMEGA( 1)=	0.48092E+01	0.35934E+01	K1= 0.38377E+00
OMEGA( 2)=	0.48092E+01	-0.35934E+01	K1= 0.38377E+00
OMEGA( 3)=	0.22990E+02	0.21035E+02	K1= 0.83909E+00
OMEGA( 4)=	0.22990E+02	-0.21035E+02	K1= 0.83909E+00
OMEGA( 5)=	0.26583E+03	-0.24747E+02	K1= 0.28533E+01
OMEGA( 6)=	0.26583E+03	0.24747E+02	K1= 0.28533E+01

1/MU= 0.030

KL= 0.075

OMEGA( 1)=	0.52368E+01	-0.39592E+02	K1= 0.17163E+00
OMEGA( 2)=	0.52368E+01	0.39592E+02	K1= 0.17163E+00
OMEGA( 3)=	0.25183E+02	0.25085E+03	K1= 0.37637E+00
OMEGA( 4)=	0.25183E+02	-0.25085E+03	K1= 0.37637E+00
OMEGA( 5)=	0.26321E+03	0.19133E+04	K1= 0.12168E+01
OMEGA( 6)=	0.26321E+03	-0.19133E+04	K1= 0.12168E+01

KL= 0.125

OMEGA( 1)=	0.51927E+01	-0.13867E+02	K1= 0.28484E+00
OMEGA( 2)=	0.51927E+01	0.13867E+02	K1= 0.28484E+00
OMEGA( 3)=	0.24978E+02	-0.87404E+02	K1= 0.62473E+00
OMEGA( 4)=	0.24978E+02	0.87404E+02	K1= 0.62473E+00
OMEGA( 5)=	0.26346E+03	-0.65233E+03	K1= 0.20289E+01
OMEGA( 6)=	0.26346E+03	0.65233E+03	K1= 0.20289E+01

KL= 0.175

OMEGA( 1)=	0.50492E+01	-0.64387E+01	K1= 0.39323E+00
OMEGA( 2)=	0.50492E+01	0.64387E+01	K1= 0.39323E+00
OMEGA( 3)=	0.24275E+02	0.39742E+02	K1= 0.86222E+00
OMEGA( 4)=	0.24275E+02	-0.39742E+02	K1= 0.86222E+00
OMEGA( 5)=	0.26431E+03	-0.26379E+03	K1= 0.28451E+01
OMEGA( 6)=	0.26431E+03	0.26379E+03	K1= 0.28451E+01

1/MU= 0.040

KL= 0.075

OMEGA( 1)=	0.52397E+01	-0.52882E+02	K1= 0.17168E+00
OMEGA( 2)=	0.52397E+01	0.52882E+02	K1= 0.17168E+00
OMEGA( 3)=	0.25196E+02	0.33517E+03	K1= 0.37647E+00
OMEGA( 4)=	0.25196E+02	-0.33517E+03	K1= 0.37647E+00
OMEGA( 5)=	0.26319E+03	-0.25596E+04	K1= 0.12167E+01
OMEGA( 6)=	0.26319E+03	0.25596E+04	K1= 0.12167E+01

KL= 0.125

OMEGA( 1)=	0.52149E+01	-0.18747E+02	K1= 0.28545E+00
OMEGA( 2)=	0.52149E+01	0.18747E+02	K1= 0.28545E+00
OMEGA( 3)=	0.25082E+02	0.11849E+03	K1= 0.62602E+00
OMEGA( 4)=	0.25082E+02	-0.11849E+03	K1= 0.62602E+00
OMEGA( 5)=	0.26333E+03	-0.89451E+03	K1= 0.20284E+01
OMEGA( 6)=	0.26333E+03	0.89451E+03	K1= 0.20284E+01

KL= 0.175

OMEGA( 1)=	0.51340E+01	-0.90847E+01	K1= 0.39652E+00
OMEGA( 2)=	0.51340E+01	0.90847E+01	K1= 0.39652E+00
OMEGA( 3)=	0.24697E+02	0.56819E+02	K1= 0.86969E+00
OMEGA( 4)=	0.24697E+02	-0.56819E+02	K1= 0.86969E+00
OMEGA( 5)=	0.26380E+03	0.40852E+03	K1= 0.28423E+01
OMEGA( 6)=	0.26380E+03	-0.40852E+03	K1= 0.28423E+01

1/MU= 0.050

KL= 0.075

OMEGA( 1)=	0.52410E+01	-0.66157E+02	K1= 0.17170E+00
OMEGA( 2)=	0.52410E+01	0.66157E+02	K1= 0.17170E+00
OMEGA( 3)=	0.25202E+02	-0.41936E+03	K1= 0.37651E+00
OMEGA( 4)=	0.25202E+02	0.41936E+03	K1= 0.37651E+00
OMEGA( 5)=	0.26319E+03	0.32045E+04	K1= 0.12167E+01
OMEGA( 6)=	0.26319E+03	-0.32045E+04	K1= 0.12167E+01

KL= 0.125

OMEGA( 1)=	0.52251E+01	0.23584E+02	K1= 0.28573E+00
OMEGA( 2)=	0.52251E+01	-0.23584E+02	K1= 0.28573E+00
OMEGA( 3)=	0.25129E+02	0.14923E+03	K1= 0.62661E+00
OMEGA( 4)=	0.25129E+02	-0.14923E+03	K1= 0.62661E+00
OMEGA( 5)=	0.26328E+03	0.11322E+04	K1= 0.20282E+01
OMEGA( 6)=	0.26328E+03	-0.11322E+04	K1= 0.20282E+01

KL= 0.175

OMEGA( 1)=	0.51733E+01	0.11647E+02	K1= 0.39804E+00
OMEGA( 2)=	0.51733E+01	-0.11647E+02	K1= 0.39804E+00
OMEGA( 3)=	0.24887E+02	0.73236E+02	K1= 0.87301E+00
OMEGA( 4)=	0.24887E+02	-0.73236E+02	K1= 0.87301E+00
OMEGA( 5)=	0.26357E+03	0.54054E+03	K1= 0.28411E+01
OMEGA( 6)=	0.26357E+03	-0.54054E+03	K1= 0.28411E+01

## APPENDIX D

### PROGRAM PANEL3

Program PANEL3 is a finite-element supersonic flutter approximation for curved panels of infinite aspect ratio with circular arc cross-section subjected to either simply-supported or clamped boundary conditions. The curved panel may be divided into a specified number of elements of equal arclength, each having four degrees-of-freedom. The four degrees-of-freedom include vertical deflection and rotation at each end of the element.

The purpose of program PANEL3 is to solve the eigenproblem represented by

$$\left[ [K] + \frac{\lambda}{\bar{N}^3} [A] \right] \{w\} = \frac{K}{\bar{N}} [M] \{w\}$$

where

$$\bar{N} = \frac{2\bar{a}_1}{\sin\left(\frac{1}{\bar{N}} \sin^{-1}(2\bar{a}_1)\right)},$$

$$\lambda = \frac{2qL^3}{D\sqrt{M^2 - 1}}$$

$[K]$  = Global stiffness matrix

$[N]$  = Global incremental stiffness matrix

$[A]$  = Global aerodynamic matrix

$[M]$  = Global mass matrix

$R_{xx}$  = Nondimensional in-plane tension parameter

$N$  = Number of finite elements

$q$  is the dynamic pressure,  $L$  is the length of the panel,  $D$  is the panel rigidity,  $M$  is the freestream Mach number, and  $K$  is the eigenvalue of the system for monotonically increasing values of the nondimensional dynamic pressure parameter,  $\lambda$ . The program determines the flutter point of the flat panel by coalescence of the two smallest eigenvalues for these increasing values of  $\lambda$ . Figure 4 demonstrates how the nondimensional dynamic pressure parameter at the flutter point varies with the maximum camber to panel length ratio,  $\bar{a}_1$ , for both the simply-supported (Figure 4(a)) and the clamped (Figure 4(b)) cases. When the maximum camber to panel length ratio is 0.0, the results indicate that the dynamic pressure parameter is equal to the value computed by program PANEL1 for a flat panel, as expected. When the panel is curved ( $\bar{a}_1 \neq 0.0$ ), the flutter value of the dynamic pressure parameter decreases, indicating that the panel is less stable.

In addition to locating the flutter point of the curved panel, program PANEL3 also determines the flutter mode shape and offers a comparison of this result with that obtained by Houbolt.<sup>6</sup> An example is given in the sample output for a simply-supported panel at a condition beyond the flutter value corresponding to  $\lambda=364$ .

Twelve of the arrays used in program PANEL3 must be dimensioned according to the number of beam finite-elements used with the maximum number of finite-elements being twelve. These arrays must be dimensioned as follows:

XSS(2N,2N)	XCL(2N-2,2N-2)
MSS(2N,2N)	MCL(2N-2,2N-2)
WSS(2N)	WCL(2N-2)
ALPHASS(2N)	ALPHACL(2N-2)
GAMMASS(2N)	GAMMACL(2N-2)
ZSS(2N,2N)	ZCL(2N-2,2N-2)

The definitions of these arrays may be found in Appendix I (Definitions of Parameters Used in Programs).

The output data files for program PANEL3, stored in the permanent directory FLUTTER, are named according to the following format:

panel3.n#a1bar

where # is the number of beam finite-elements used and  $\bar{a}_1$  is the maximum camber to the panel length ratio used. For example, if the file containing output data, for the case where four beam finite-elements are used to model a curved panel with a maximum camber to panel length ratio of 0.05, is to be viewed, the correct syntax of the file name is panel3.n45. A condensed listing of this sample output data file can be found on the following pages.

# LISTING OF SAMPLE OUTPUT

## PROGRAM PANEL3

\*\*\*\*\*  
\*\*\*\*\* SUPersonic PANEL FLUTTER ANALYSIS (PANEL3) \*\*\*\*\*  
\*\*\*\*\*

N= 4      A1BAR=0.050

\*\*\*\*\*SIMPLY-SUPPORTED BOUNDARY CONDITION\*\*\*\*\*

LAMBDA= 0.000

K(1)=	96.54071	0.00000
K(2)=	1561.04733	0.00000

LAMBDA= 10.000

K(1)=	97.02941	0.00000
K(2)=	1560.91300	0.00000

LAMBDA= 20.000

K(1)=	98.49638	0.00000
K(2)=	1560.50917	0.00000

LAMBDA= 30.000

K(1)=	100.94421	0.00000
K(2)=	1559.83337	0.00000

LAMBDA= 40.000

K(1)=	104.37729	0.00000
K(2)=	1558.88143	0.00000

LAMBDA= 50.000

K(1)=	108.80182	0.00000
K(2)=	1557.64743	0.00000

\*\*\*\*\*FLUTTER POINT (EIGENVALUE COALESCENCE)\*\*\*\*\*

LAMBDA= 340.236

K(1)=	1036.30501	0.00000
K(2)=	1036.30696	0.00000

\*\*\*\*\*FLUTTER MODE SHAPE\*\*\*\*\*

W( 1)=	-0.11303	0.00000
W( 2)=	0.05281	0.00000
W( 3)=	0.07900	0.00000
W( 4)=	-0.24619	0.00000
W( 5)=	0.48152	0.00000
W( 6)=	-0.59930	0.00000
W( 7)=	-0.00897	0.00000
W( 8)=	-1.00000	0.00000

\*\*\*\*\*HOUBOLT FLUTTER MODE COMPARISON\*\*\*\*\*

LAMBDA= 364.310

K(1)=	1067.12989	-282.91884
K(2)=	1067.12989	282.91884

\*\*\*\*\*FLUTTER MODE SHAPE\*\*\*\*\*

W( 1)=	0.10927	0.06397
W( 2)=	-0.05460	-0.06345
W( 3)=	-0.06850	0.05268
W( 4)=	0.23098	-0.07630
W( 5)=	-0.47296	-0.03320
W( 6)=	0.59008	-0.02119
W( 7)=	-0.00769	-0.05207
W( 8)=	1.00000	0.00000

\*\*\*\*\*CLAMPED BOUNDARY CONDITION\*\*\*\*\*

LAMBDA= 0.000

K(1)=	497.31466	0.00000
K(2)=	3845.05316	0.00000

LAMBDA= 10.000

K(1)=	497.64877	0.00000
K(2)=	3844.97885	0.00000

LAMBDA= 20.000

K(1)=	498.65129	0.00000
K(2)=	3844.75575	0.00000

LAMBDA= 30.000

K(1)=	500.32271	0.00000
K(2)=	3844.38339	0.00000

LAMBDA= 40.000

K(1)=	502.66391	0.00000
K(2)=	3843.86098	0.00000

LAMBDA= 50.000

K(1)=	505.67607	0.00000
K(2)=	3843.18741	0.00000

\*\*\*\*\*FLUTTER POINT (EIGENVALUE COALESCENCE)\*\*\*\*\*

LAMBDA= 632.150

K(1)=	2699.47549	0.00000
K(2)=	2699.47729	0.00000

\*\*\*\*\*FLUTTER MODE SHAPE\*\*\*\*\*

W( 1)=	-0.10707	0.00000
W( 2)=	-0.02561	0.00000
W( 3)=	0.43301	0.00000
W( 4)=	-0.99427	0.00000
W( 5)=	1.00000	0.00000
W( 6)=	0.43627	0.00000

\*\*\*\*\*HOUBOLT FLUTTER MODE COMPARISON\*\*\*\*\*

LAMBDA= 648.745

K(1)=	2699.47549	0.00000
K(2)=	2699.47729	0.00000

\*\*\*\*\*FLUTTER MODE SHAPE\*\*\*\*\*

W( 1)=	0.10707	0.00000
W( 2)=	0.02561	0.00000
W( 3)=	-0.43301	0.00000
W( 4)=	0.99427	0.00000
W( 5)=	-1.00000	0.00000
W( 6)=	-0.43627	0.00000



## APPENDIX E

### PROGRAM PANEL4

Program PANEL4 is a finite-element supersonic flutter approximation for curved panels of infinite aspect ratio with circular arc cross-section subjected to either simply-supported or clamped boundary conditions. The curved panel may be divided into a specified number of beam finite-elements of equal arclength, each having six degrees-of-freedom. The six degrees-of-freedom include vertical deflection, horizontal deflection, and rotation at each end of the element.

The purpose of program PANEL4 is to solve the eigenproblem represented by

$$\left[ [K] + \frac{\lambda}{\bar{N}^3} [A] \right] \{w\} = \frac{K}{\bar{N}^4} [M] \{w\}$$

where

$$\bar{N} = \frac{2\bar{a}_1}{\sin \left( \frac{1}{\bar{N}} \sin^{-1} (2\bar{a}_1) \right)},$$

$$\lambda = \frac{2qL^3}{D\sqrt{M^2 - 1}}$$

$[K]$  = Global stiffness matrix

$[N]$  = Global incremental stiffness matrix

$[A]$  = Global aerodynamic matrix

$[M]$  = Global mass matrix

$R_{xx}$  = Nondimensional in-plane tension parameter

$N$  = Number of finite elements

$q$  is the dynamic pressure,  $L$  is the length of the panel,  $D$  is the panel rigidity,  $M$  is the freestream Mach number, and  $K$  is the eigenvalue of the system for monotonically increasing values of the nondimensional dynamic pressure,  $\lambda$ . The program determines the flutter point of the curved panel by coalescence of the two smallest eigenvalues for monotonically increasing values of the nondimensional dynamic pressure parameter,  $\lambda$ . Figure 5 demonstrates how the nondimensional dynamic pressure parameter at the flutter point varies with the maximum camber to panel length ratio,  $\bar{a}_1$ , for both the simply-supported (Figure 5(a)) and the clamped (Figure 5(b)) cases. For the simply-supported case,  $\lambda$  decreases when  $\bar{a}_1$  increases. For the clamped case,  $\lambda$  increases when  $\bar{a}_1$  increases, which is in contrast with the trend predicted by program PANEL3. The difference is due to the additional two degrees-of-freedom (horizontal displacements) of each finite-element of the curved panel modeled by PANEL4. In addition to determining the flutter

point of the curved panel, program PANEL4 also determines the flutter mode shape.

Twelve of the arrays used in program PANEL4 must be dimensioned according to the number of beam finite-elements used with the maximum number of finite-elements currently limited to eleven. (For this program, the number of beam finite-elements must also be odd.) These arrays must be dimensioned as follows:

XSS(3N-1,3N-1)	XCL(3N-3,3N-3)
MSS(3N-1,3N-1)	MCL(3N-3,3N-3)
WSS(3N-1)	WCL(3N-3)
ALPHASS(3N-1)	ALPHACL(3N-3)
GAMMASS(3N-1)	GAMMACL(3N-3)
ZSS(3N-1,3N-1)	ZCL(3N-3,3N-3)

The definitions of these arrays may be found in Appendix I (Definitions of Parameters Used in Programs).

The output data files for program PANEL4, stored in the permanent directory FLUTTER, are named according to the following format:

panel4.n#a1bar

where # is the number of beam finite-elements used and  $\bar{a}_1$  is the ratio of the maximum camber to the panel length used. For example, if the file containing output data, for the case where four beam finite-elements are used to model a curved panel with a maximum camber to panel length ratio of 0.05, is to be viewed, the correct syntax of the output file name is panel4.n45. A condensed listing of the sample output data file can be found on the following pages.

# LISTING OF SAMPLE OUTPUT

## PROGRAM PANEL4

\*\*\*\*\*  
 \*\*\*\*\* SUPersonic PANEL FLUTTER ANALYSIS (PANEL4) \*\*\*\*\*  
 \*\*\*\*\*

N= 5      A1BAR=0.050

\*\*\*\*\*SIMPLY-SUPPORTED BOUNDARY CONDITION\*\*\*\*\*

LAMBDA= 0.000

K(1)=	0.00000	0.00000
K(2)=	0.00000	0.00000

LAMBDA= 10.000

K(1)=	96.72867	0.00000
K(2)=	1552.83157	0.00000

LAMBDA= 20.000

K(1)=	98.19498	0.00000
K(2)=	1552.19460	0.00000

LAMBDA= 30.000

K(1)=	100.64346	0.00000
K(2)=	1551.53116	0.00000

LAMBDA= 40.000

K(1)=	104.07752	0.00000
K(2)=	1550.64927	0.00000

LAMBDA= 50.000

K(1)=	108.50312	0.00000
K(2)=	1549.52001	0.00000

\*\*\*\*\*FLUTTER POINT (EIGENVALUE COALESCENCE)\*\*\*\*\*

LAMBDA= 342.268

K(1)=	1041.75469	0.00000
K(2)=	1041.76094	0.00000

\*\*\*\*\*FLUTTER MODE SHAPE\*\*\*\*\*

W( 1)=	0.11177	0.00000
W( 2)=	0.04437	0.00000
W( 3)=	-0.07189	0.00000
W( 4)=	-0.00552	0.00000
W( 5)=	-0.00904	0.00000
W( 6)=	0.09497	0.00000
W( 7)=	-0.34884	0.00000
W( 8)=	0.04383	0.00000
W( 9)=	0.54687	0.00000
W(10)=	-0.45161	0.00000
W(11)=	0.02473	0.00000
W(12)=	0.71305	0.00000
W(13)=	0.25538	0.00000
W(14)=	1.00000	0.00000

\*\*\*\*\*CLAMPED BOUNDARY CONDITION\*\*\*\*\*

LAMBDA= 0.000

K(1)=	0.00000	0.00000
K(2)=	0.00000	0.00000

LAMBDA= 10.000

K(1)=	494.35664	0.00000
K(2)=	3830.66013	0.00000

LAMBDA= 20.000

K(1)=	495.61002	0.00000
K(2)=	3816.38383	0.00000

LAMBDA= 30.000

K(1)=	497.33332	0.00000
K(2)=	3813.49853	0.00000

LAMBDA= 40.000

K(1)=	499.69901	0.00000
K(2)=	3812.18092	0.00000

LAMBDA= 50.000

K(1)=	502.72940	0.00000
K(2)=	3811.23054	0.00000

\*\*\*\*\*FLUTTER POINT (EIGENVALUE COALESCENCE)\*\*\*\*\*

LAMBDA= 638.917

K(1)=	2726.31210	0.00000
K(2)=	2726.32393	0.00000

\*\*\*\*\*FLUTTER MODE SHAPE\*\*\*\*\*

W( 1)=	0.11513	0.00000
W( 2)=	-0.10297	0.00000
W( 3)=	0.09168	0.00000
W( 4)=	-0.01486	0.00000
W( 5)=	0.10659	0.00000
W( 6)=	-0.61164	0.00000
W( 7)=	0.11288	0.00000
W( 8)=	0.95534	0.00000
W( 9)=	-0.79702	0.00000
W(10)=	0.02581	0.00000
W(11)=	1.00000	0.00000
W(12)=	0.88804	0.00000

## APPENDIX F

### PROGRAM TRESPAN

Program TRESPAN is a transient response analysis for a flat panel of infinite aspect ratio subjected to a supersonic flow. The program analyzes a transient response for flat panels subjected to either simply-supported or clamped boundary conditions.

The real and imaginary parts of the panel first eigenvalue determined in program PANEL1 for both the simply-supported and clamped cases are input parameters for program TRESPAN. Program TRESPAN uses these input parameters, along with the panel first natural frequency,  $\omega_r$ , and incremental values of the aerodynamic damping coefficient,  $g_\alpha$ , to find the transient response of the panel.

Program TRESPAN also creates a line plot of the panel transient response which is shown, in a condensed form, for both the simply-supported and the clamped cases, on the following pages.

The output data file for program TRESPAN, stored in the permanent directory FLUTTER, is named according to the following format:

trespan.dat

# LISTING OF SAMPLE OUTPUT

## PROGRAM TRESPAN

\*\*\*\*\*SIMPLY-SUPPORTED BOUNDARY CONDITION\*\*\*\*\*

	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30
133 I							*						I
134 I							1*4						I
135 I							1*4.						I
136 I							12*						I
137 I						1	234						I
138 I						1	234						I
139 I						1	2	34					I
140 I						1	23	4					I
141 I						1	2	3	4				I
142 I						1	2	34					I
143 I						1	2	34					I
144 I						1	23	4					I
145 I						1	2	34					I
146 I						1	234						I
147 I						1	234						I
148 I						1	2*						I
149 I							12*						I
150 I							**						I
151 I							*						I
152 I							4*1						I
153 I							.4321						I
154 I							.432	1					I
155 I							.432	1					I
156 I							.4	3	2	1			I
157 I							.4	3	2	1			I
158 I							.4	3	2	1			I
159 I							.4	3	2	1			I
160 I							.4	3	2	1			I
161 I							.4	3	2	1			I
162 I							.4	3	2	1			I
163 I							.4	3	2	1			I
164 I							.4	3	2	1			I
165 I							.43	2	1				I
166 I							.43	2	1				I
167 I							.43	2	1				I
168 I							.4321						I
169 I							4*1						I
170 I							*						I
171 I							12*						I
172 I						1	234						I
173 I						1	2	34					I
174 I						1	2	34					I
175 I						1	2	3	4				I
176 I						1	2	3	4				I
177 I						1	2	3	4				I
178 I						1	2	3	4				I
179 I						1	2	3	4				I

\*\*\*\*\*CLAMPED BOUNDARY CONDITION\*\*\*\*\*

	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30
	+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+												
130 I							**						I
131 I							1*						I
132 I							1234						I
133 I						1	2 34						I
134 I					1	2 34.							I
135 I				1	2 3 4.								I
136 I			1	2 3 4.									I
137 I			1	2 3 4.									I
138 I			1	2 3 4.									I
139 I				1	2 34.								I
140 I					1	234.							I
141 I						1 234							I
142 I						1*							I
143 I						*21							I
144 I						432	1						I
145 I						.43	2	1					I
146 I						.4	3	2	1				I
147 I						.4	3	2		1			I
148 I						.43	2			1			I
149 I						.43	2			1			I
150 I						.4	3	2		1			I
151 I						.4	3	2	1				I
152 I						.43	2	1					I
153 I						432	1						I
154 I						*							I
155 I						1	2*						I
156 I					1	2 34							I
157 I				1	2 34.								I
158 I			1	2 3 4.									I
159 I		1	2 3 4.										I
160 I	1	2 3 4.											I
161 I	1	2 3 4.											I
162 I	1	2 3 4.											I
163 I		1	2 34.										I
164 I			1	2 3 4									I
165 I				1	234								I
166 I					*								I
167 I					432	1							I
168 I					.43	2	1						I
169 I					.4	3	2	1					I
170 I					.4	3	2		1				I
171 I					.4	3	2			1			I
172 I					.4	3	2				1		I
173 I					.4	3	2				1		I
174 I					.4	3	2			1			I
175 I					.4	3	2	1					I
176 I					.43	2	1						I
177 I					432	1							I



## APPENDIX G

### SUBROUTINE: GVCRG

Subroutine GVCRG is required to find all of the eigenvalues and eigenvectors of the generalized, real eigensystem represented by  $A*w=\lambda*B*w$ . The subroutine is accessed from the International Mathematical Subroutines Library (IMSL) on the CRAY-2 computer (Voyager, at NASA Langley Research Center) and is called from programs PANEL1, PANEL3, and PANEL4.

Subroutine GVCRG may be called using the following statement where each of the arguments is briefly described below:

CALL GVCRG (N,A,LDA,B,LDB,ALPHA,GAMMA,EVEC,LDEVEC)

#### Input Arguments

- N Order of the matrices A and B
- A Full, real matrix of order N
- LDA Leading dimension of A exactly as specified in the DIMENSION statement of the calling program
- B Full, real matrix of order N
- LDB Leading dimension of B exactly as specified in the DIMENSION statement of the calling program

#### Output Arguments

- ALPHA Complex vector of length N
- GAMMA Vector of length N;  
The J-th eigenvalue is  $ALPHA(J)/GAMMA(J)$ , assuming  $GAMMA(J)$  is not zero. If  $GAMMA(J)$  is zero then the eigenvalue is to be regarded as infinite.
- EVEC Complex matrix of order N;  
The J-th eigenvector, corresponding to  $ALPHA(J)/GAMMA(J)$  is stored in the J-th column.
- LDEVEC Leading dimension of EVEC exactly as specified in the DIMENSION statements of the calling program

Additional information regarding subroutine GVCRG may be obtained by using the on-line documentation system *imsl*doc located in the directory */usr/local/unsupported/bin*.

To link the IMSL library to the aforementioned programs, the option *-limslib* must be added to the *cf77* command line. For example, to load the IMSL library to program PANEL1, the proper syntax upon compilation is:

*cf77 -limslib -o panell panell.f*

where *panell* is the specified executable file.

## APPENDIX H

### SUBROUTINE GVLRG

Subroutine GVLRG is required to find all of the eigenvalues and eigenvectors of the generalized, real eigensystem represented by  $A*w=\lambda*B*w$ . The subroutine is accessed from the International Mathematical Subroutines Library (IMSL) on the CRAY-2 computer (Voyager, at NASA Langley Research Center) and is called from programs PANEL2A and PANEL2B.

Subroutine GVLRG may be called using the following statement where each of the arguments is briefly described below:

CALL GVLRG (N,A,LDA,B,LDB,ALPHA,GAMMA)

#### Input Arguments

- N Order of the matrices A and B
- A Full, real matrix of order N
- LDA Leading dimension of A exactly as specified in the DIMENSION statement of the calling program
- B Full, real matrix of order N
- LDB Leading dimension of B exactly as specified in the DIMENSION statement of the calling program

#### Output Arguments

- ALPHA Complex vector of length N
- GAMMA Vector of length N;  
The J-th eigenvalue is ALPHA(J)/GAMMA(J), assuming GAMMA(J) is not zero. If GAMMA(J) is zero then the eigenvalue is to be regarded as infinite.

Additional information regarding subroutine GVLRG may be obtained by using the on-line documentation system *imsl*doc located in the directory */usr/local/unsupported/bin*.

To link the IMSL library to the aforementioned programs, the option *—limslib* must be added to the *cf77* command line. For example, to load the IMSL library to program PANEL2A, the proper syntax upon compilation is:

*cf77 —limslib —o panel2a panel2a.f*

where *panel2a* is the specified executable file.

## APPENDIX I

### DEFINITIONS OF PARAMETERS USED IN PROGRAMS

The following parameters are used in programs PANEL1, PANEL2A, PANEL2B, PANEL3, and PANEL4:

- A Panel aerodynamic matrix
- ACL Panel aerodynamic matrix upon application of clamped boundary conditions
- AE Element aerodynamic matrix
- ALPHACL Vector numerator of eigenvalues for clamped case
- ALPHASS Vector numerator of eigenvalues for simply-supported case
- ASS Panel aerodynamic matrix upon application of simply-supported boundary conditions
- GAMMACL Vector denominator of eigenvalues for clamped case
- GAMMASS Vector denominator of eigenvalues for simply-supported case
- K Panel stiffness matrix
- KCL Panel stiffness matrix upon application of clamped boundary conditions
- KE Element stiffness matrix
- KSS Panel stiffness matrix upon application of simply-supported boundary conditions
- LAMBDA Dynamic pressure parameter
- M Panel mass matrix
- MCL Panel mass matrix upon application of clamped boundary conditions
- ME Element mass matrix
- MSS Panel mass matrix upon application of simply-supported boundary conditions
- N Number of beam finite-elements
- NN Panel incremental stiffness matrix

NCL Panel incremental stiffness matrix upon application of clamped boundary conditions  
 NE Element incremental stiffness matrix  
 NSS Panel incremental stiffness matrix upon application of simply-supported boundary conditions  
 RXX Nondimensional in-plane tension parameter  
 WCL Matrix of eigenvalues for clamped case  
 WSS Matrix of eigenvalues for simply-supported case  
 XCL Matrix on left hand side of eigenproblem for clamped case  
 XSS Matrix on left hand side of eigenproblem for simply-supported case  
 YCL Matrix on right hand side of eigenproblem for clamped case  
 YSS Matrix on right hand side of eigenproblem for simply-supported case  
 ZCL Matrix of eigenvectors for clamped case  
 ZSS Matrix of eigenvectors for simply-supported case

In addition to the above parameters, programs PANEL2A and PANEL2B use the following parameters as well:

APMR Air-panel mass ratio  
 KL Reduced frequency parameter

In addition to the parameters listed above, programs PANEL3 and PANEL4 also use the following parameters:

A1BAR Maximum camber to panel length ratio  
 ALF Element orientation angle

The following parameters are used in program TRESPAN:

**GALPHA** Aerodynamic damping coefficient  
**OMEGAR** Panel first natural frequency (for the simply-supported case)

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Houbolt, J. C., "A Study of Several Aerothermoelastic Problems of Aircraft Structures in High-Speed Flight," Doctoral Thesis, Swiss Federal Institute of Technology, Zurich, Switzerland, Prom. Nr. 2760 (1958).

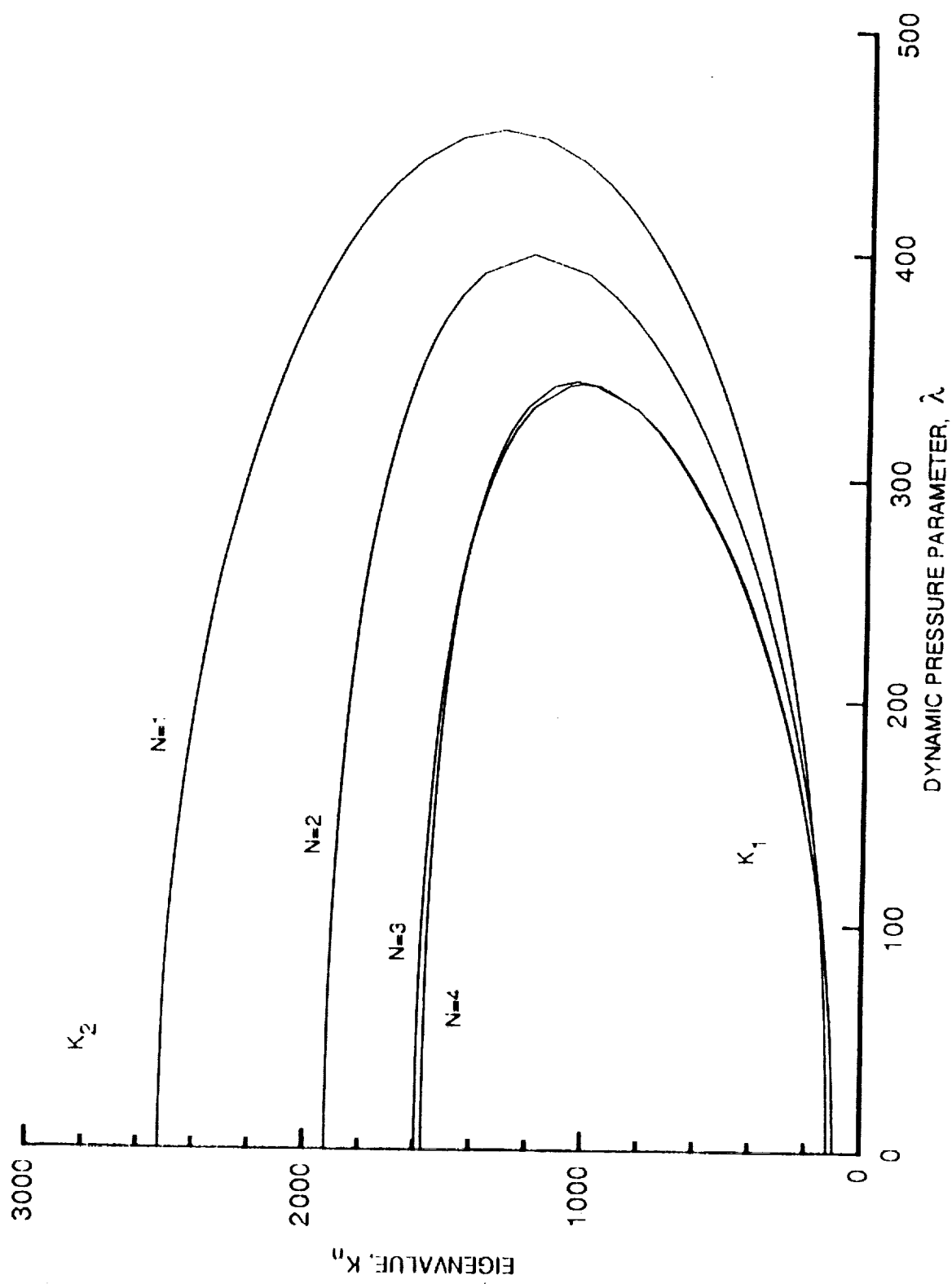


Figure 1(a) - Eigenvalue coalescence for simply-supported flat panel predicted by program PANEL1.



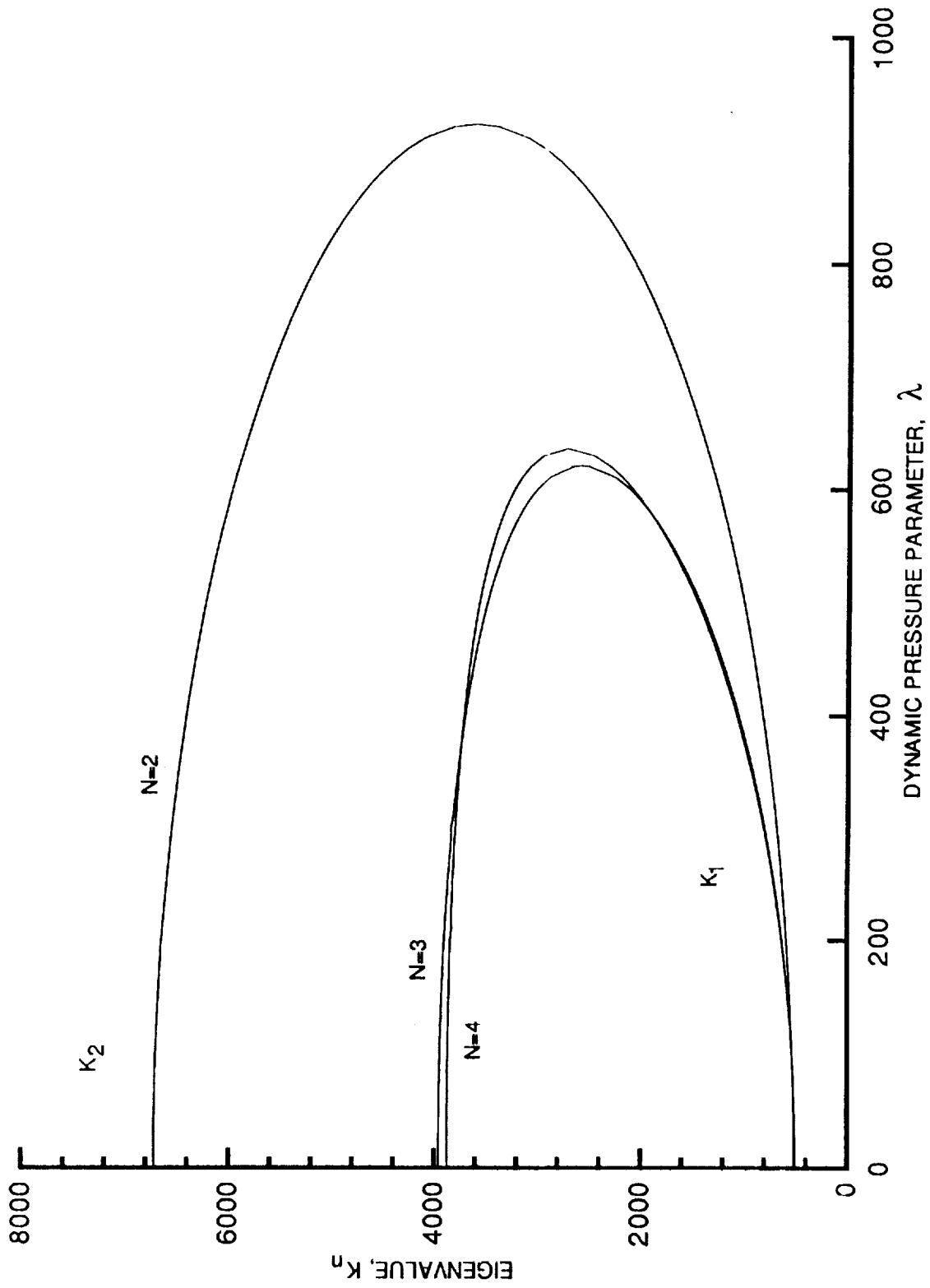


Figure 1(b) - Eigenvalue coalescence for clamped flat panel predicted by program PANEL1.

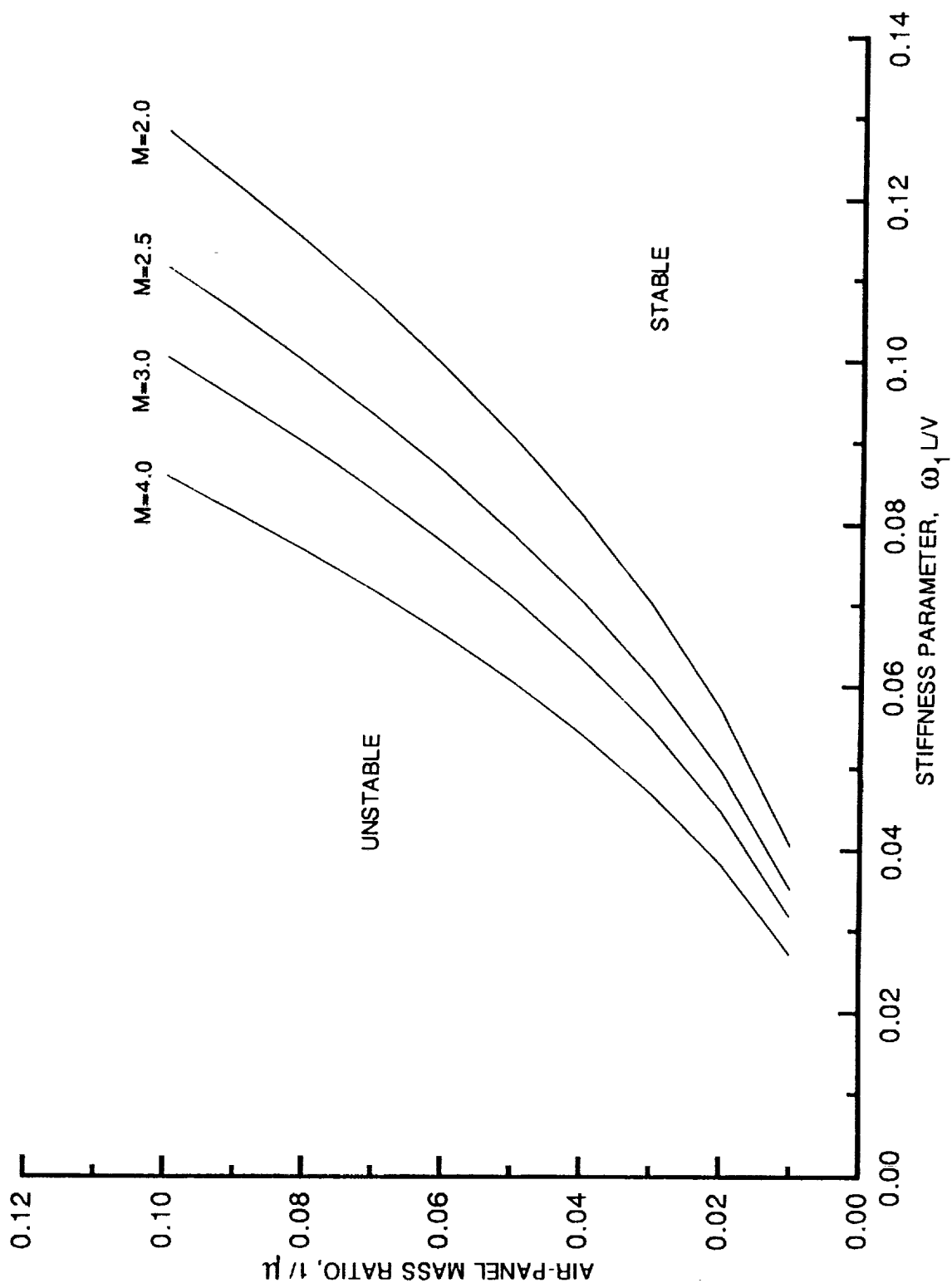


Figure 2 - Air-panel mass ratio vs. stiffness parameter for a simply-supported flat panel at various Mach numbers predicted by program PANEL2A.

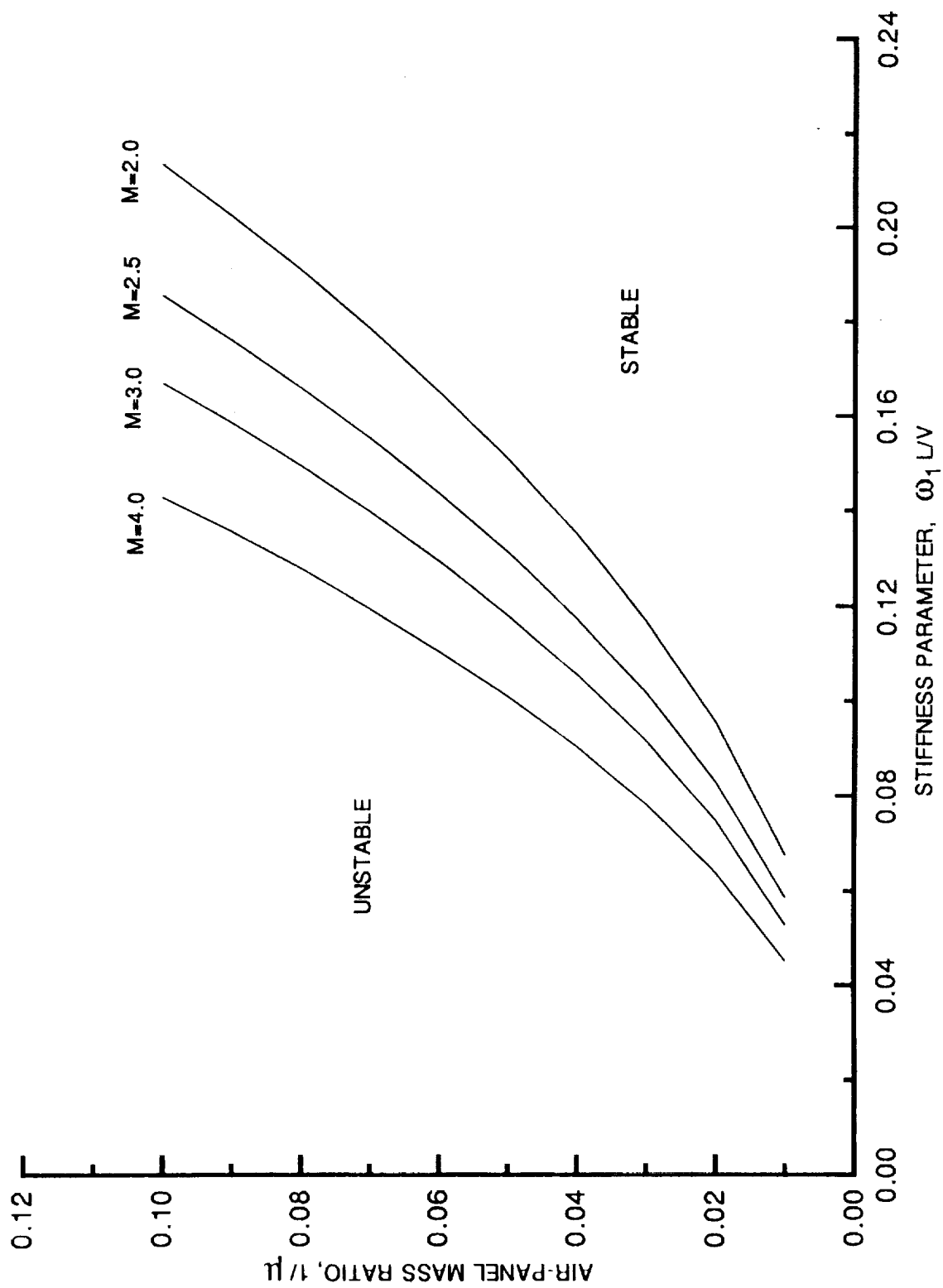


Figure 3 - Air-panel mass ratio vs. stiffness parameter for a clamped flat panel at various Mach numbers predicted by program PANEL2B.

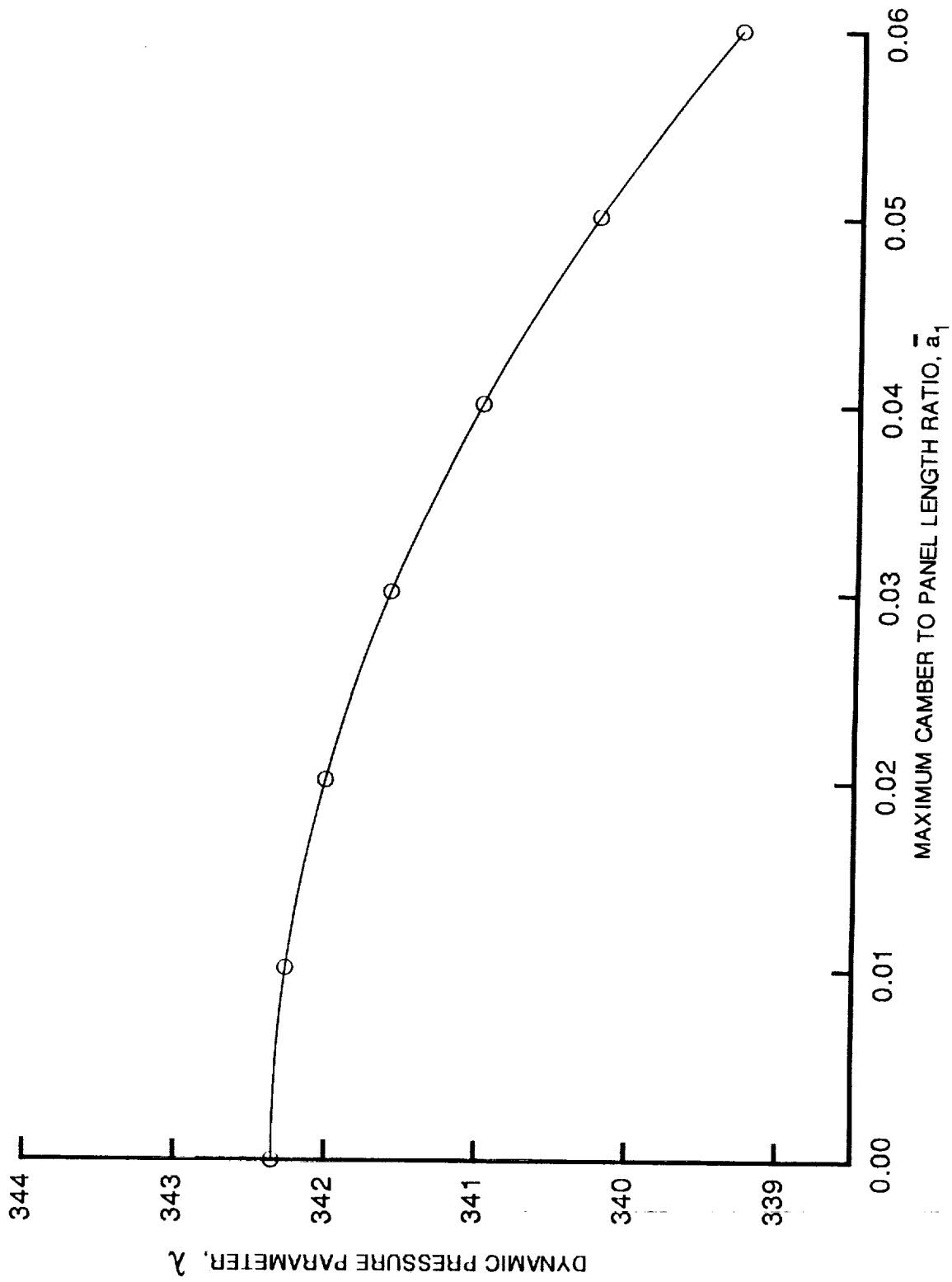


Figure 4(a) - Dynamic pressure at flutter vs. maximum camber for a simply-supported panel modeled using four finite-elements, each having four degrees-of-freedom, predicted by program PANEL3.

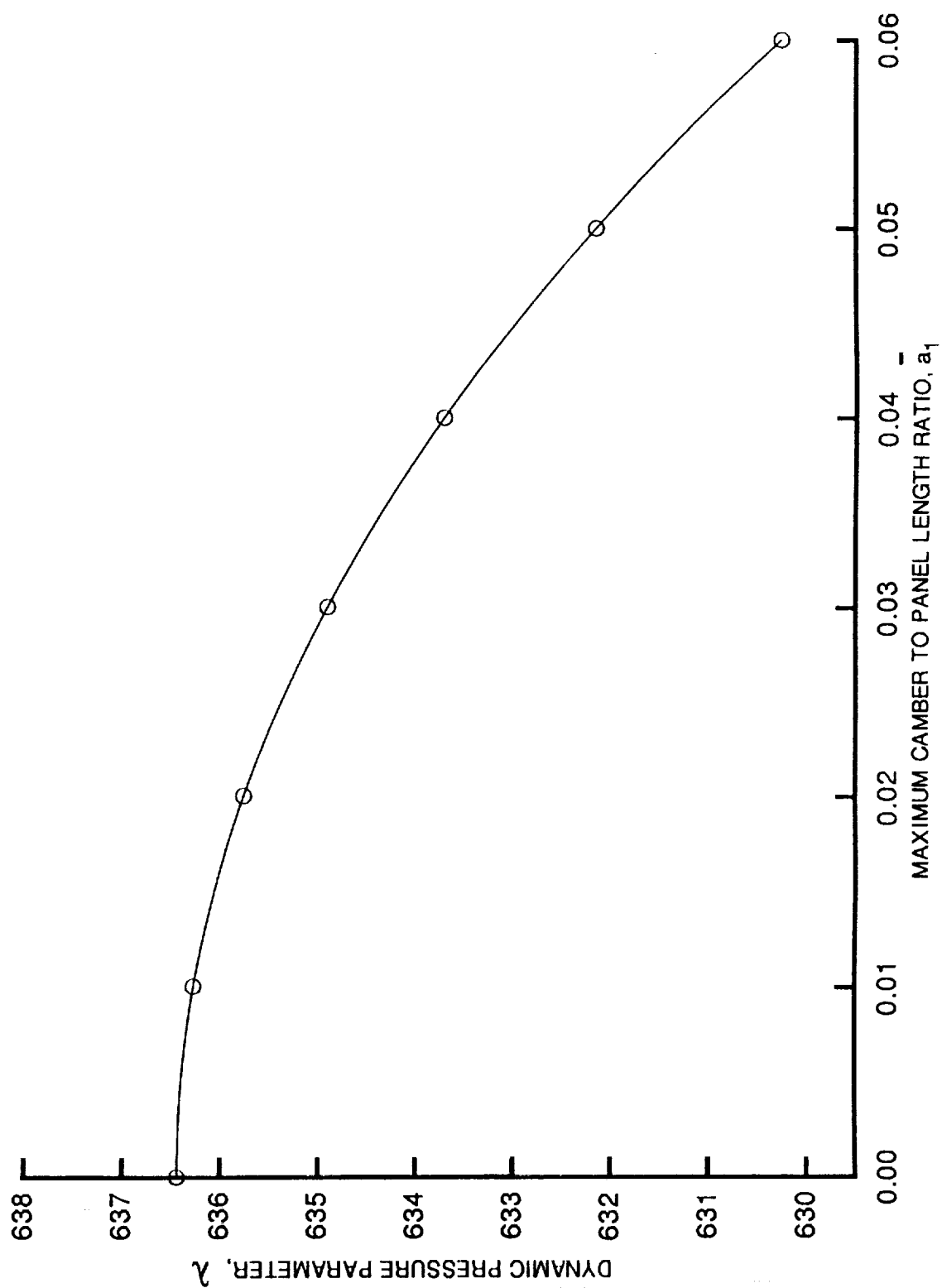


Figure 4(b) - Dynamic pressure at flutter vs. maximum camber for a clamped panel modeled using four finite-elements, each having four degrees-of-freedom, predicted by program PANEL3.

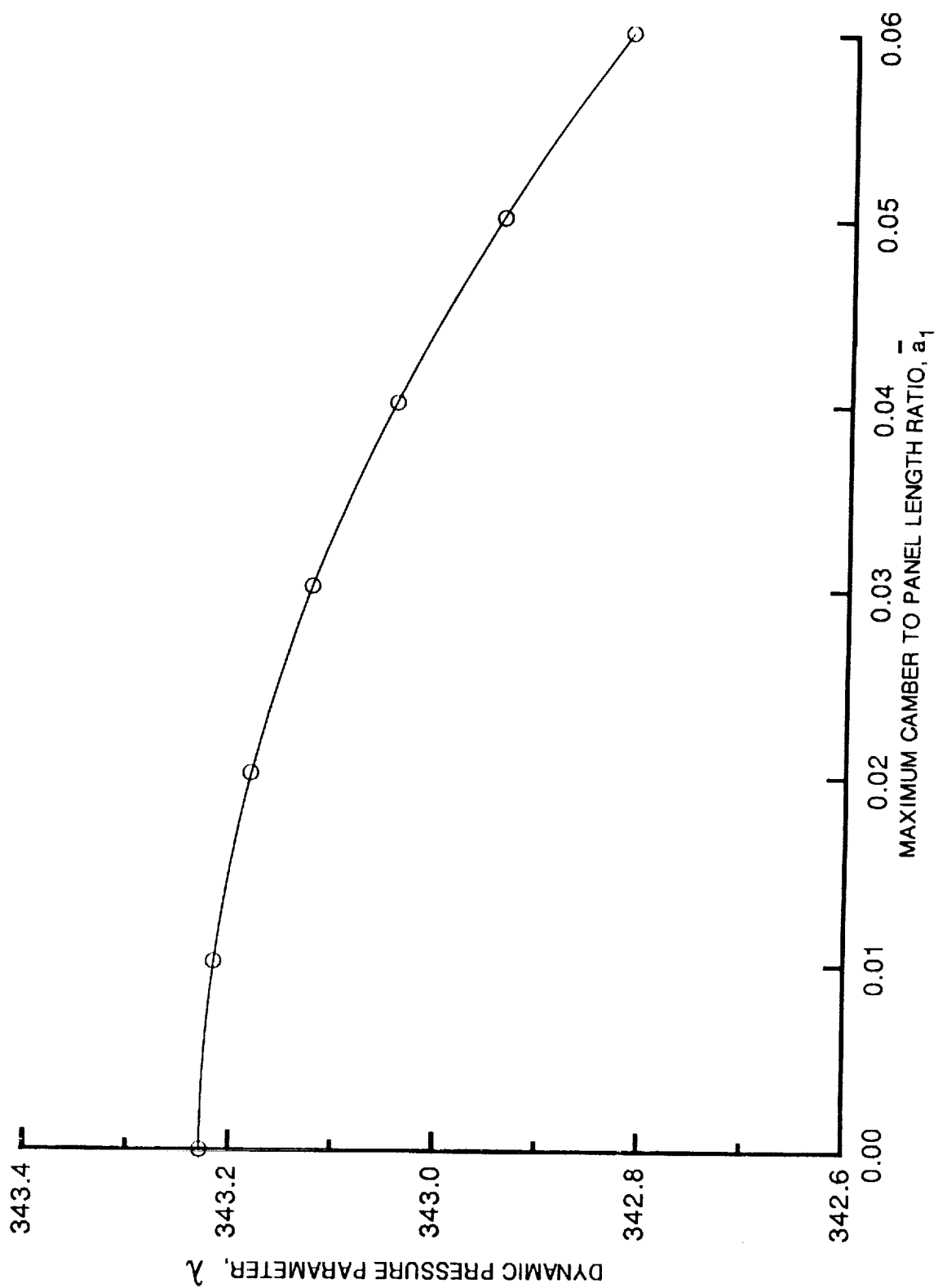


Figure 5(a) - Dynamic pressure at flutter vs. maximum camber for a simply-supported panel modeled using four finite-elements, each having six degrees-of-freedom, predicted by program PANEL4.

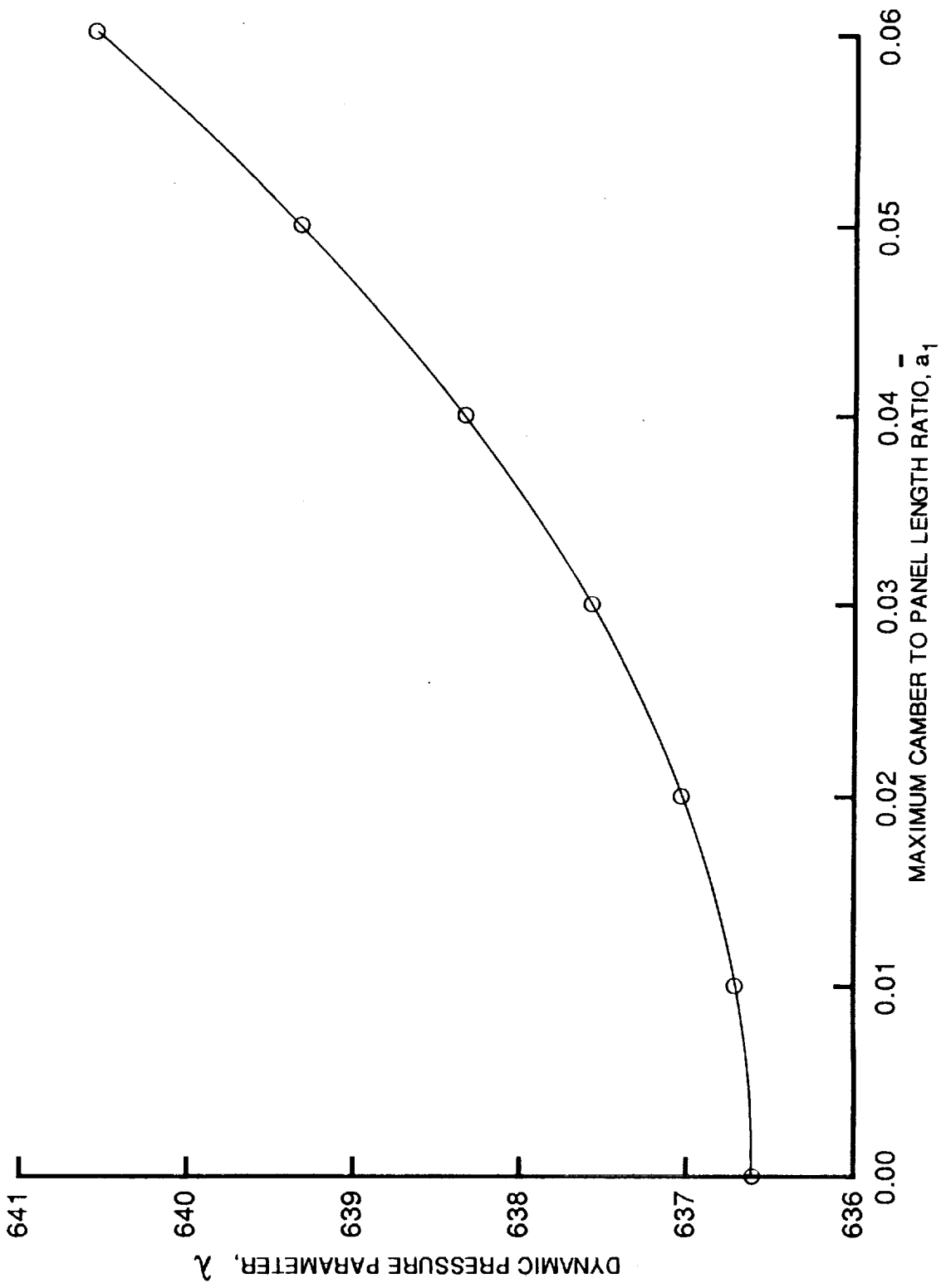


Figure 5 (b) - Dynamic pressure at flutter vs. maximum camber for a clamped panel modeled using four finite-elements, each having six degrees-of-freedom, predicted by program PANEL4.

# Report Documentation Page

1. Report No.  NASA TM 104109		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle  User's Guide to a System of Finite-Element Supersonic Panel Flutter Programs				5. Report Date  July 1991	
				6. Performing Organization Code	
7. Author(s)  Christine L. Woolley and John T. Batina				8. Performing Organization Report No.	
				10. Work Unit No.  509-10-02-03	
9. Performing Organization Name and Address  NASA Langley Research Center Hampton, Virginia 23665-5225				11. Contract or Grant No.	
				13. Type of Report and Period Covered  Technical Memorandum	
12. Sponsoring Agency Name and Address  National Aeronautics and Space Administration Washington, DC 20546-0001				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract  The utilization and operation of a set of six computer programs for the prediction of panel flutter at supersonic speeds by finite-element methods are described. The programs run individually to determine the flutter behavior of a flat panel where the finite-elements which model the panel each have four degrees-of-freedom, a curved panel where the finite-elements each have four degrees-of-freedom, and a curved panel where the finite-elements each have six degrees-of-freedom. The panels are assumed to be of infinite aspect ratio and are subjected to either simply-supported or clamped boundary conditions. The aerodynamics used by these programs are based on piston theory. Application of the programs is illustrated by sample cases where the number of beam finite-elements equals four, the in-plane tension parameter is 0.0, the maximum camber to panel length ratio for a curved panel case is 0.05, and the Mach number is 2.0. This memorandum provides a user's guide for these programs, describes the parameters that are used, and contains sample output from each of the programs.					
17. Key Words (Suggested by Author(s))  Aeroelasticity Panel Flutter Unsteady Aerodynamics Supersonic Aerodynamics			18. Distribution Statement  Unclassified - Unlimited  Subject Category 02		
19. Security Classif. (of this report)  Unclassified		20. Security Classif. (of this page)  Unclassified		21. No. of pages  53	
				22. Price  A04	